Performance Analysis for Smooth Power Generation of WECS System Using ANN/PI Based Control Techniques

Vinaya Rana, M.A. Ansari, Yogesh K. Chauhan

***Abstract*: In this paper, the physical control techniques of tip speed ratio and blade pitch angle of wind energy conversion system for smooth power generation has been demonstrated. To extract smooth power from WECS, it is required to control the system in such a way that it must produce a constant torque. ANN and PI are the most effective control techniques for the optimal control of TSR and BPA to maintain the constant torque. The proposed system contains the design of ANN and PI based controller for performance analysis of WECS. MATLAB/Simulink environment is used to implement the system to test on different uncertain conditions of wind. The obtained results are found suitable with the design ANN and PI based controller WECS system.**

Keywords: Blade pitch angle, control techniques, Tip speed ratio, controller

I. INTRODUCTION

Most of the electrical energy generation is depend on the fossil fuel which is depleting day by day and harming the environment. It is very important to find the alternating power generation sources, which are environment friendly. Renewable energy (RE) is the most emerging area for research due to its various positive effect on environment and human life. Climate alteration due to the emission of CO_2 is making the use of RE furthermost attractive [1]. Wind and solar RE sources are freely and abundantly available on the earth. India has a great potential of wind energy and standing at fourth position in the world in this area. Wind energy is the most increasing RE source among different types of RE [2].

The wind energy system is extremely desirable to contribute as an important role for power generation in future. The increasing potential of wind energy has been driven by multiplicity factor by government of India to provide subsidies on the renewable energy [3]. Wind energy over the last few decade has become the most attractive technology for clean and sustainable energy production. The wind energy generation of last five years is shown in Fig.1. In 2015, the wind installed capacity was 21.13 GW which is increasing 14.95 GW in last five years [4].

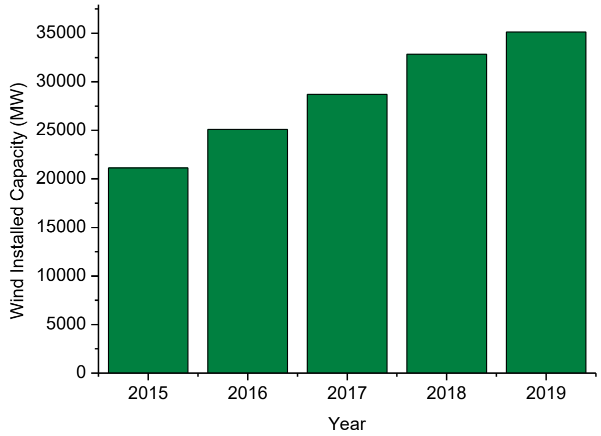

Fig. 1.Installed capacity of during last 5 year [4]

If the speed of wind is within the permissible limits, then wind turbine (WT) should generate constant power. A simulation based power regulation using PID controller for BPA control has been design. The design controller efficiently maintaining the constant torque for wind turbine [5]. For the controlling of WT a self-tune adaptive fuzzy logic controller is design. The membership function for this controller are extracted using artificial bee colony technique. The comparative analysis has been done between the conventional PID and adaptive fuzzy logic controller [6]. CFD calculation is used to formulate the function of pitch angle control for WT. The control technique is increasing the generated power by 6.6 %, when pitch angle is adjusted using this technique [7]. The authors in [8] have analysed the hybrid fuzzy-PID control technique for WT and the results are compared using different control techniques. In [9], the modeling of variable pitch and variable speed WT is investigated to achieve the maximum power from the WT. A PB-SMC technique for PMSG is to extract the maximum power from WT is used. The output of close loop system is always positive via energy reforming and the system robustness for various parameters of PMSG is improved using SMC [10]. The BPA control of floating WT with experimental results has been analysed using loop control and the result shows that the controller is performing the efficient to reduce the pitch motion of WT. For large WT, the control of TSR is presented [11].

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* Correspondence Author
Vinaya Rana*, EED, SOE, Gautam Buddha University, Greater Noida, India.
M. A. Ansari, EED, SOE, Gautam Buddha University, Greater Noida, India.
Yogesh K. Chauhan, EED, KNIT, Sultanpur, India.

The large inertia of rotor shaft has also been taken in to account for designing the non-linear controller. The results are compared with conventional control techniques and non-linear control technique is more suitable for large WT.

The proposed diagram of a ANN/PI based BPA and TSR control techniques is shown in Fig.2. The BAP and TSR is controlled by ANN/PI, to achieve the constant torque.

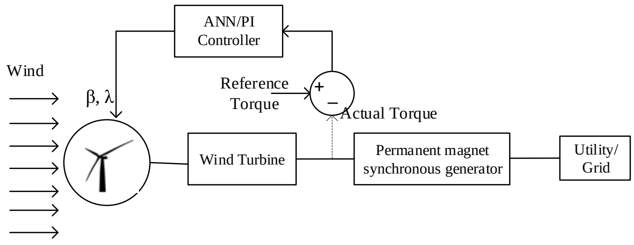


Fig. 2.Block diagram representation of proposed control techniques

The origination of this paper is divided into five sections. In first section, introduction part about the wind energy availability, requirements and its benefits. Literature review of pervious research work related to the BPA and TSR control has also been considered in this section. Section II includes the mathematical modeling of both WECS and PMSG. The ANN/PI based control techniques for controlling the BPA and TSR are described in section III. Section IV describe the results and discussion of the proposed control techniques and section V conclude the effectiveness of this research work.

II. MODELING OF WECS AND PMSG

The modeling of WT is based the kinetic energy of the rotor. The output power of WT in terms of mechanical power [5,7] is given in (1).

$$P_{mech.} = 0.5\rho_a A.C_{Power}(\lambda,\beta).v^3 \quad (1)$$

Where, $P_{mech.}$ is mechanical power, ρ_a is density of air (kg/m^3), A= WT swept area, v is wind flow (m/s), C_{Power} is coefficient of power, β is blade pitch angle and λ is tip speed ratio.

The TSR and coefficient of power of WT are given in (2) to (4),

$$\lambda(TSR) = \frac{\omega_r R}{v} \quad (2)$$

$$C_p(\lambda,\beta) = P_1\left(\frac{P_2}{\lambda_i} - P_3.\beta\right)e^{-\frac{P_5}{\lambda_i}} + P_6\lambda \quad (3)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1} \quad (4)$$

Where, the ω_r is rotor speed and R is radius and the coefficients P_1 to P_6 are constants and values of these coefficients are as: $P_1 = 0.5176$, $P_2 = 116$, $P_3 = 0.4$, $P_4 = 5$, $P_5 = 21$ and $P_6 = 0.0068$.

The modeling of PMSG is done in d-q reference frame [9] as shown in (5) to (6) as below:

$$\frac{dI_d}{dt} = \frac{1}{l_{ds}+l_{ls}}\left(-r_s i_d + \omega_e\left(l_{qs}+l_{ls}\right)i_q + u_d\right) \quad (5)$$

$$\frac{dI_q}{dt} = \frac{1}{l_{qs}+l_{ls}}\left(-r_s i_q + \omega_e\left(l_{qs}+l_{ls}\right)i_q + u_d\right) \quad (6)$$

Where, r_s is the resistance of stator, l_d and l_q are the generator inductance on d and q axis and l_{ls} is generator leakage inductance, and ω_e is rotating speed (rad/s) of PMSG.

The electromagnetic torque (ETM) (T_m) of generator is given by (7) as,

$$T_m = 1.5p((l_{ds} - l_{ls})i_d i_q + i_q\psi_f \quad (7)$$

Where, i_d and i_q are the d-q axis current and Ψ_f is permanent magnetic flux.

III. CONTROL TECHNIQUES

Proportional Integral (PI) based controller is used to obtain the error signal between the reference set point and the output of the system as shown in Fig.3.

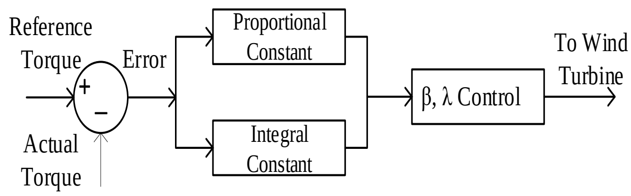


Fig. 3.PI controller

The mathematical formula of PI controller is shown in (8).

$$v(t) = K_p e(t) + K_i \int e(t)dt \quad (8)$$

Where, *Ki and Kp* are integral and proportional constants respectively. These constant are tuned to minimize the different of reference value and actual value. The fluctuating torque is used as the input to the PI controller. The error function generated by the controller is used to optimize BPA and TSR of WT.

The designed feed forward ANN is implemented to control the torque. The smooth torque control technique based on the output of ANN is considered as BPA and TSR. The ANN is trained according to the data considered for wind speed variation by the various hidden layers to the desired output of WT. The mathematical model of ANN is given in (9).

$$O_n^h = \sum_{m=1}^{p} w_{mn}x_m + \theta_m^h \text{ and } O_{n+1}^o = \sum_{n=1}^{p} w_{m(n+1)}O_n^h + \theta_n^o \quad (9)$$

Where, $W_{mn,}$ and $W_{n(n+1)}$ are the weight of the hidden layers. θ_m^h and θ_n^o the bias value of the hidden layer and output layer respectively. x_m and O_n^h are input and output of the hidden layer.

IV. RESULTS AND DISCUSSION

The wind speed is variable in nature, the speed of the WT is varying from 11.2 to 15 m/s in different format as shown in Fig. 4.

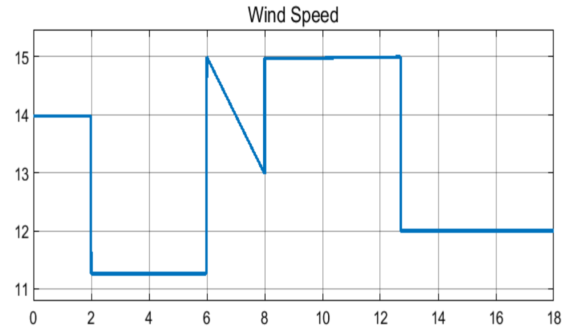


Fig. 4.Wind Speed For Wecs System

The wind speed is constant (14 m/s) from 0 to 2 sec, the wind speed is drastically change and reached 11.2 m/s from 2 to 6 sec. From 6 to 8 sec, the wind speed is continuously changing from 15 to 13 m/s and again reached to 15 m/s from 8 to 12.5 sec after 12.5 sec the wind speed is constant at 12m/s as shown in table 1.

TABLE 1: CASE STUDY OF ANN/PI BASED TRS AND BPA CONTROLLER FOR WECS

Case-1	Case-2	Case-2	Case-4	Case-5
0 – 2 sec	2-6 sec	6-8 sec	8-12.5 sec	12.5-18 sec
14 m/s	11.2 m/s	15 – 13 m/s	15 m/s	12 m/s

The proposed simulation diagram of ANN/PI control techniques is also shown in Fig. 5.

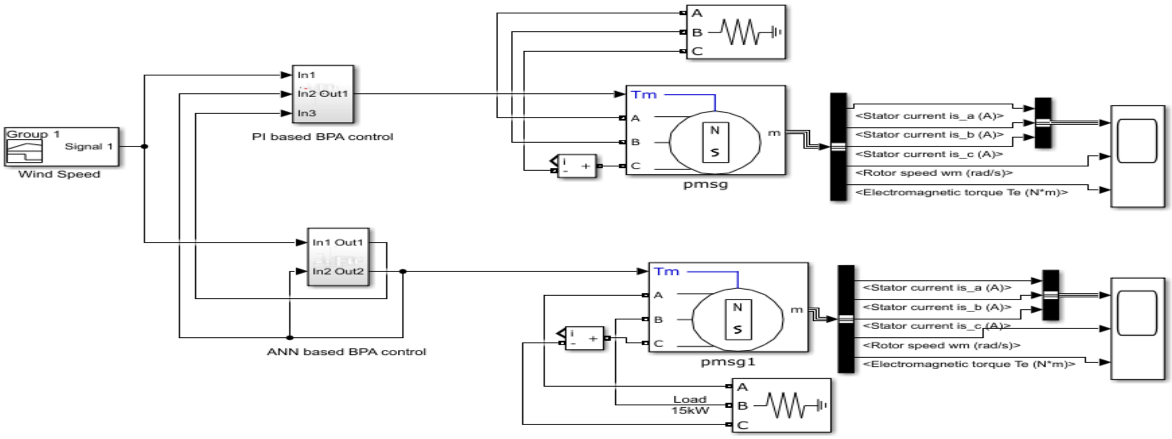
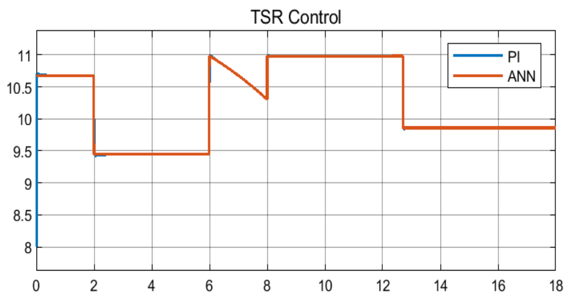


Fig. 5.Proposed simulation diagram for WT.

The TSR and BPA control techniques is used to control the turbine torque. The tip speed and blade pitch of turbine is achieved by ANN is very fast as compare to PI controller as shown in Fig.6(a)-(b).



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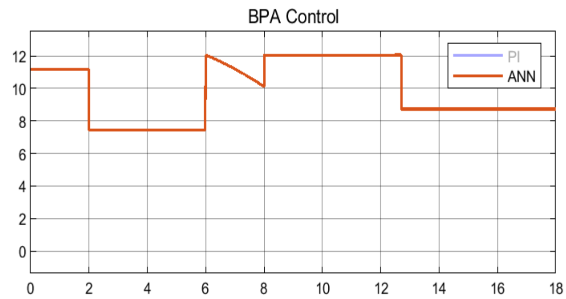
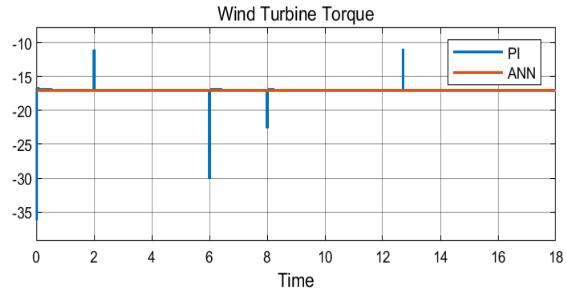


(b)

Fig. 6.TSR and BPA control techniques

The torque of the turbine is shown in Fig.7(a)-(b) as



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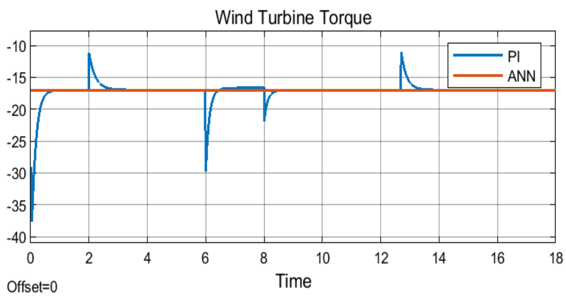
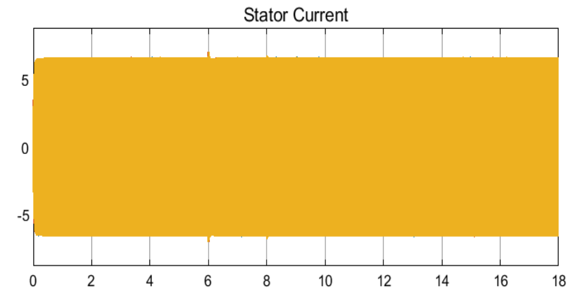


(b)

Fig. 7.Turbine torque for TSR and BPA control techniques

The torque is control by TSR and BPA techniques. As the speed of turbine is varying at the specific time, then the torque is also varying but due to the error minimization it has achieved smoothly very fast by ANN as compare to PI.The speed of rotor, current of stator and EMT of PMSG based on PI are shown in Fig.8(a), Fig.9(a) and Fig.10(a) respectively. The speed of rotor, current of stator and EMT of PMSG based on ANN are shown in Fig.8(b), Fig.9(b) and Fig.10(b) respectively. The stator current of the PMSG is 6.7 ampere, when the speed of turbine is constant about 14 sec. The rotational speed of rotor and torque of generator is 260 rad/sec and -16.94 Nm respectively at same time in both controllers. The speed of rotor and generator torque is more smooth in ANN based controller as compare to the PI based controller.



(a)

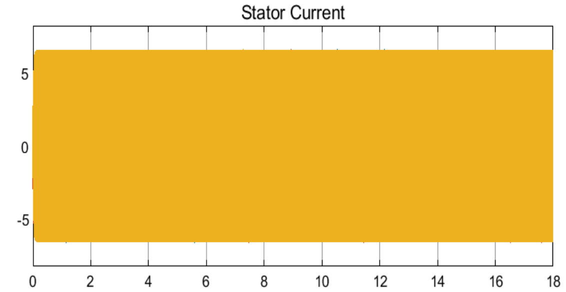


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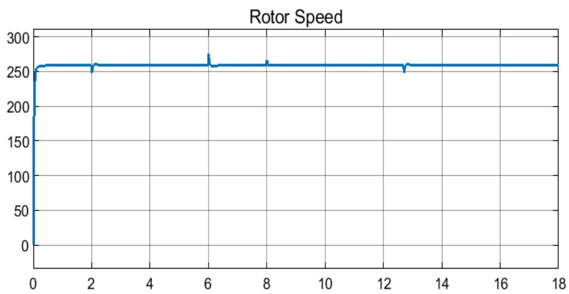
Fig. 8.Induced stator current of generator based on TSR



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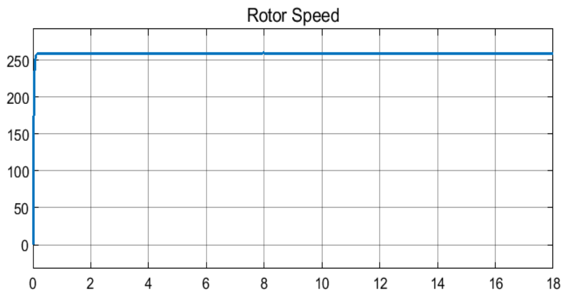
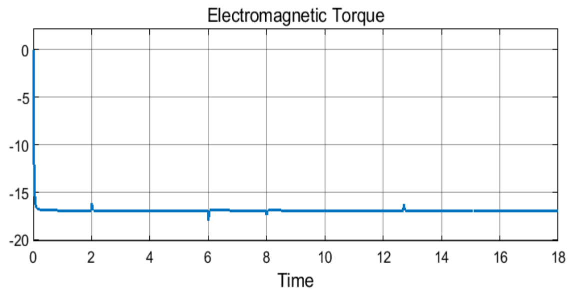


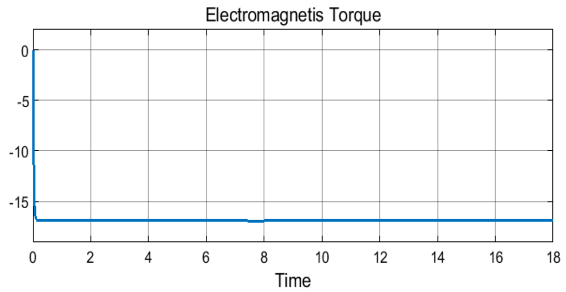
(b)

Fig. 9.Speed of rotor based on TSR

The voltage and current of 15 kW resistive load is shown in Fig.11(a) and (b) are the voltage of resistive load for PI and ANN based controller. The voltage and current both are varying as the turbine speed is varying in case of PI based controller and voltage and current both are constant in ANN based TSR controller. At the steady state condition, the voltage and current across load are 762 V and 6.6 A respectively. The current of the resistive load for both controllers are shown in Fig.12(a) and (b) respectively.

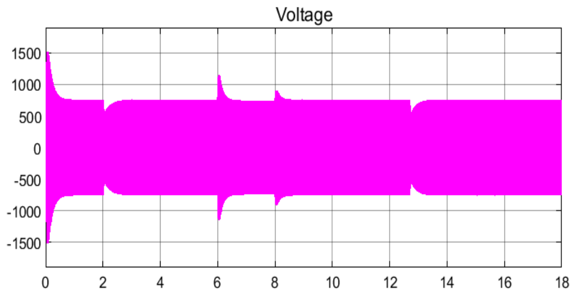


(a)



(b)

Fig. 10. EMT Of Generator Using TSR Control



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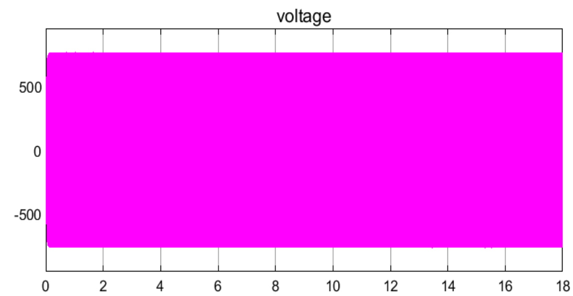
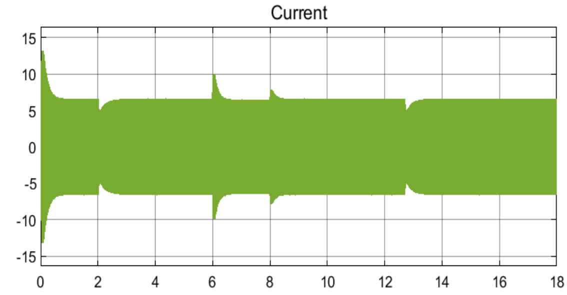


(b)

Fig. 11. Voltage profile of resistive load (TSR control)

The speed of rotor, induced stator current and EMT of BPA control techniques based PMSG are shown in Fig.13-15 respectively. The stator current is varied as the wind speed is varied at the particular time describe in table 1.

The speed variation is more in PI based controller as compared to ANN based controller. The EMT and the speed of rotor of generator is also varying with respect to turbine speed. The speed of rotor, induced stator current and EMT based on PI and ANN control techniques are 6.6 A, 260 rad/sec and -16.92 Nm respectively at 14 sec.



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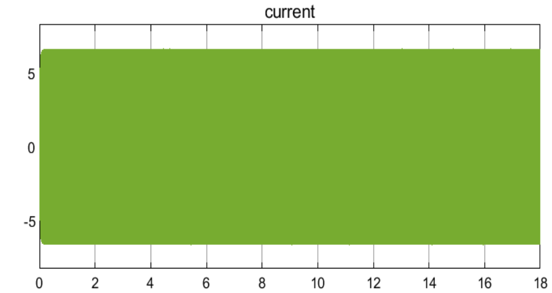

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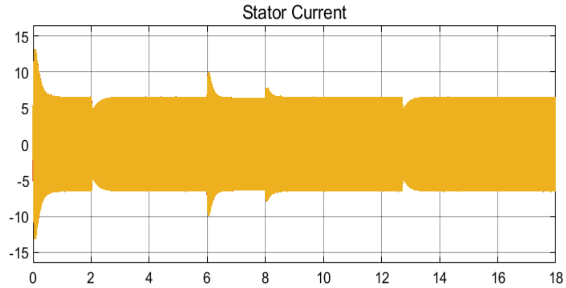
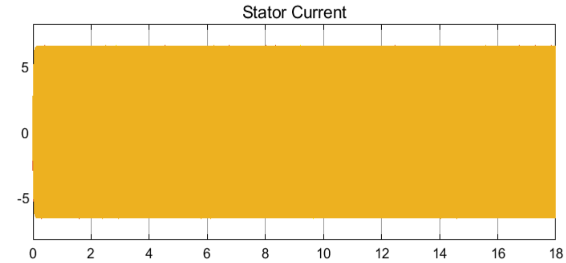
Fig. 12. Current profile of resistive load (TSR control)

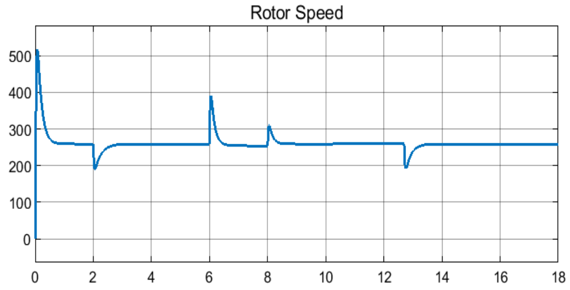


(a)



(b)

Fig. 13. Induced stator current of generator based on TSR



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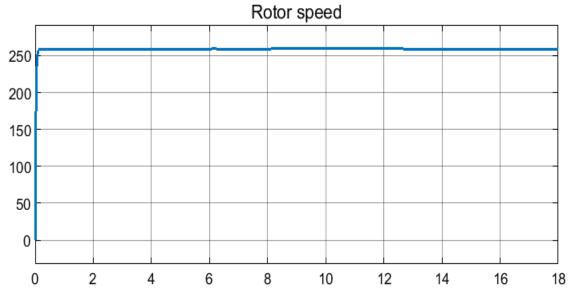

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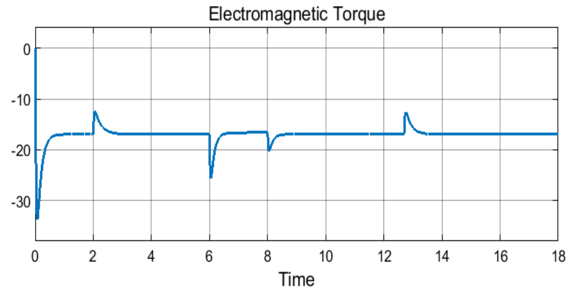
Fig. 14. Speed of rotor based on TSR



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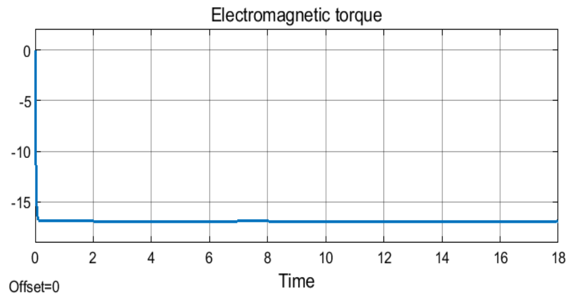
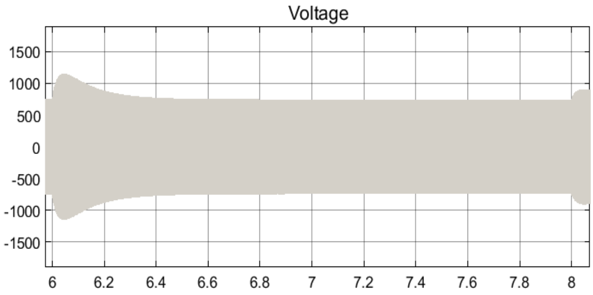


(b)

Fig. 15. EMT of generator using TSR control

A 15 kW load is used to analysed the behaviour the system. The voltage profile of the load is shown in Fig.16(a) and (b). The current is shown in Fig.17(a) and (b) respectively. The load current and voltage is varying as the turbine speed is vary and constant after few second. Finally, the voltage across the load is 765 V and current is 6.6 A.



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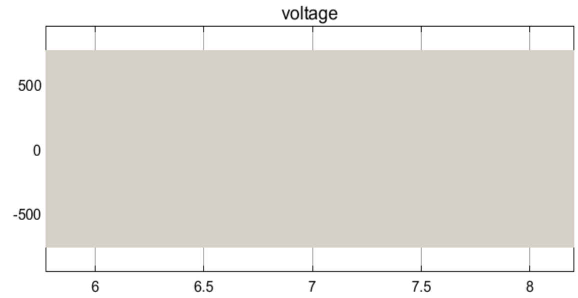
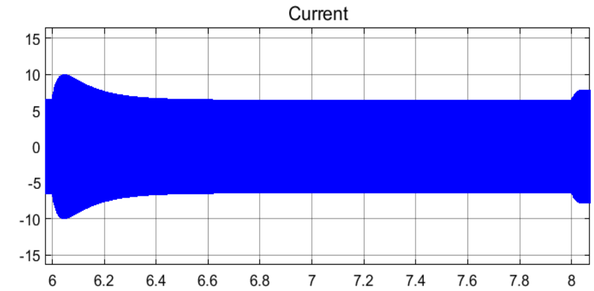


(b)

Fig. 16. Voltage of resistive load during case 3 (BPA Control)



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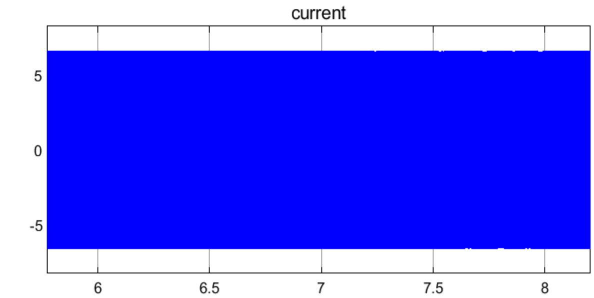

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Fig. 17. Current of resistive load during case 3 (BPA Control)

V. CONCLUSION

Controlling of the parameters BPA and TSR for wind turbine has been designed, simulated and analysed in this paper. This work shows that the controlling of torque developed by WECS has been done successfully using both PI/ANN controlling technique. The proposed system is designed and validated on MATLAB/Simulink environment. Smooth power generation in uncertain wind speed is the main objective of this research work which has been achieved. ANN based control techniques is working very accurately as complain to PI control technique. The torque error is significantly reduced in ANN based BPA and TSR control scheme. The stator current, rotor speed and EMT is also attain very quickly. So the ANN based controller is most stabile for this study.

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AUTHORS PROFILE

Vinaya Rana obtained his B.Tech. in Electrical and Electronics Engineering from AKTU, Lucknow in 2010, and M.Tech. in Power System Engineering from EED, School of Engineering, Gautam Buddha University, Greater Noida, India in 2013. He is currently working towards his Ph.D. degree from EED, School of Engineering, Gautam Buddha University, Greater Noida, India.

M.A.Ansari received B.Tech.(Electrical Engineering) in 1998 from Aligarh Muslim University, India, M.Tech.(Electrical Engineering) and Ph.D. in 2001 and 2009 respectively from Indian Institute of Technology, Roorkee, India. The author has taught in several National and International universities globally. He is currently associated with the Department of Electrical Engineering, School of Engineering, Gautam Buddha University, Gr. Noida, NCR Delhi, India. His research interests include digital image processing, Biomedical Instrumentation & Control, bio-energy and renewable energy. He is a senior member of IEEE and has published more than 100 papers in national and international Journals & Conferences and has guided several M.Tech. dissertations and PhDs.

Yogesh K. Chauhan obtained his B. Tech. in Electrical Engineering from G.B. Pant University of Agriculture & Technology, Uttarakhand in 1997, M. Tech. from IIT Delhi in 1998 and Ph. D. from Thapar University, Patiala, Punjab, India in 2010. He is currently working as an Associate Professor in EED, Kamla Nehru Institute of Technology, Sultanpur, India. His research interests include power electronics & drive and renewable energy. He has published many papers in national and international Journals & Conferences and guided many M.Tech. and PhDs.